# NATURAL DECAY RESISTANCE OF HEARTWOOD FROM DEAD, STANDING YELLOW-CEDAR TREES: LABORATORY EVALUATIONS

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ABSTRACT

Yellow-cedar trees have been mysteriously dying for more than a century in southeast Alaska. As these stems continue to stand for decades in the forest, foliage, twigs, and branches deteriorate. The sapwood in the stem degrades, leaving columns of essentially heartwood standing like ghosts in the forest until they eventually drop. To estimate the potential for utilization of these trees, several experiments have been initiated to characterize the natural durability of heartwood from dying and dead yellow-cedar trees. The objectives of this study were to characterize the durability of heartwood in living and dead stems using standard American Society for Testing and Materials procedures and to determine if durability of heartwood differs between living and dead trees, with tree size, with position relative to pith, and with years following tree death. Results from this study indicate that the heartwood from live trees and from snag class III trees was resistant to attack by *G. trabeum*. Heartwood from smaller diameter trees in snag class V was moderately resistant to *G. trabeum,* but heartwood from the larger diameter trees in snag class V was not. Heartwood of live and dead yellow-cedar trees was not resistant to decay by *Postia placenta* and *Serpula himantioides*. Results also suggest that the natural durability against decay fungi of clear heartwood from living yellow-cedar trees and from yellow-cedar trees that have been dead less than 80 years is adequate to have practical application for products used aboveground and subjected to intermittent wetting.

Yellow-cedar *(Chamaeqparis nootkatensis)* trees have been mysteriously dying for more than a century in southeast Alaska (7-9). Trees of all sizes, ages, and crown classes have been affected (12). As these stems stand for decades in the forest, foliage, twigs, and branches deteriorate **(Table 1).** The sapwood in the stem degrades, leaving columns of essentially heartwood standing like ghosts in the forest until they eventually drop.

The heartwood of yellow-cedar is recognized as having some degree of natural durability. There are more than 500,000 acres of dead yellow-cedar trees in the forest (7). These trees could be a large and valuable timber resource if the persistent heartwood columns of the dead trees could be used in value-added applications where natural durability is required. To estimate the potential of these trees, several experiments have been initiated to characterize the natural durability of heartwood from living and dead yellow-cedar trees. The objectives of the study reported herein were to characterize the durability of heartwood in living and dead stems using standard American Society for Testing and Materials (ASTM) procedures and to determine if durability differs between living and dead trees, with tree size, with position in the bole, and with years following tree death. Results from laboratory studies with heartwood samples derived from trees harvested in Southeast Alaska are reported here.

## LITERATURE REVIEW

The heartwood of cedar is listed in the *Wood Handbook (4)* as being resistant or very resistant to decay. The heartwood of Alaska yellow-cedar is specifically described in the *Wood Handbook* as being

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*TABLE 1. – Condition of dead stems (snags) at approximate years following tree death.* [a]

| Snag class | Appearance | Average years after death |
|---|---|---|
| I | Foliage retained | 4 |
| II | Foliage gone, twigs retained | 14 |
| III | Secondary branches retained | 26 |
| IV | Only primary branches retained | 51 |
| V | No branches retained, boles intact | 81 |
| VI | Boles broken and deteriorated | Not determined |

[a] From reference (9).

*TABLE 2. – Design of field sampling protocol.*

| Snag class | Diameter | | No. of trees felled |
|---|---|---|---|
| | (mm) | (in.) | |
| Live | 300 to 400 | 12 to 16 | 20 |
| | 425 to 535 | 17 to 21 | 20 |
| III | 300 to 400 | 12 to 16 | 10 |
| | 425 to 535 | 17 to 21 | 10 |
| V | 300 to 400 | 12 to 16 | 10 |
| | 425 to 535 | 17 to 21 | |

very resistant to decay, but this classification does not seem to be universally supported by published results from decay studies.

Several reports suggest that yellow-cedar heartwood has some resistance against attack by several species of termites. Resistance to drywood (sometimes referred to as "powderpost") termites *(Cryptotermes brevis)* was reported in 1924 (17). Against the Formosan subterranean termites *(Coptotermes formosanus)*, the natural resistance of yellow-cedar compared favorably with preservative-treated wood when evaluated in accelerated tests (5). Pressed paneling mats made from yellow-cedar exhibited anti-feedant properties against *Reticulitermes flavipes* (Isoptera: Rhinotermididae) (10). Yellow-cedar fiber without wax and resin treatments, normally used in paneling production, was not a preferred food source in choice tests. However, the same fiber sustained severe damage when provided as the only food source for *R. flavipes* in no-choice tests.

Decay resistance of clear, yellow-cedar heartwood differs with fungi (14). Clear heartwood is resistant to *Lenzites saepiaria (Gloeophyllum sepiarium),* a brown-rot fungus on dead wood of a wide range of coniferous hosts (6), and to *Fomes roseus (Fomitopsis rosea),* a heart-rot fungus. However, clear heartwood is not resistant to *Poria incrassata (Meruliporia incrassata). Lenzites saepiaria (Gloeophyllum sepiarium)* occurs in Alaska (6) and is an important brown-rot fungus in wood products used aboveground in the southeastern portion of the contiguous 48 states. *P. incrassata* is a soil-inhabiting, water-conducting brown-rot fungus.

Smith and CseIJesi (15) showed that several unidentified fungi can grow in the heartwood of yellow-cedar, causing a condition recognized as black stain. These fungi appear to degrade nootkatin or 2-hydroxy-4-isopropyl-5-isopentenyl-2,4,6-cycloheptatrien-l-one (15), which occurs in the heartwood of yellow-cedar. Naturally infected dark-stained heartwood is more susceptible to decay fungi than is clear heartwood. This difference is particularly important for *L. saepiaria* and *F. roseus.* Clear yellow-cedar heartwood is resistant to attack by those fungi, but the dark-stained wood is not resistant. *P. incrassata* also causes more decay in dark-stained wood than in clear heartwood, but this is of little practical importance because of the susceptibility of clear heartwood to this fungus.

Prior studies have shown that natural decay resistance can vary among trees of the same species, within boles of individual trees, with radial and longitudinal position, and for some species, with wood density. In general, there seems to be no clear relationship between growth rate and natural durability (13). However, in western redcedar and larch, the resistance to decay is weakly related to the rate at which the wood was grown, being slightly greater as the number of rings per inch increases (3). With western larch, but not with western redcedar, decay resistance is correlated with specific gravity of the wood.

Prominent radial as well as vertical differences in decay resistance occur in heartwood of western redcedar. The outer, lower (towards the base of the tree) heartwood is the most resistant, and the inner heartwood is the least resistant (3). This same pattern also occurs in western larch, but to a lesser degree. Unlike redwood, there is no apparent relationship between decay resistance and the growing site for trees of western redcedar or western larch or with the age or size of the tree.

The natural decay resistance of heartwood in Coast redwoods *(Sequoia sempervirens* (D. Don) Endl.) varies markedly within individual trees (2). In the first one or two logs, from the butt, resistance decreases progressively from outer to inner heartwood, but there is no significant variation in resistance in relation to height above the butt log. The prevalence of very resistant outer heartwood varies among localities, presumably reflecting genetic differences between stands. Overall, very resistant heartwood is about five times more prevalent in old-growth trees than in young-growth trees. Tree age and size are also important factors associated with the natural durability of heartwood in black locust and in the oaks (11).

## METHODS

Yellow-cedar trees on the Tongass National Forest were selected according to a sampling protocol that met the needs of several mutually related endeavors **(Table 2).** Living trees, dead trees that had lost foliage and twigs but not their secondary branches (Snag Class III), and dead trees that had lost all their branches but still had their tops intact (Snag Class V) were selected. Two diameter classes were sampled in each class, namely 300 to 400 mm (12 to 16 in.) and 425 to 535 mm (17 to 21 in.) at breast height. Twenty live trees were harvested per diameter class, and 10 dead trees were harvested per diameter by group combination. Trees were felled in September 1996. As trees were felled, a 1250-cm (50-in.) length was cut from the bole at breast height. This length of tree stem was long sectioned into halves. One half length was then shipped to the USDA Forest Service, Forest Products Laboratory, in Madison, Wis. Two radially cut boards from each half section were conditioned to a constant weight in a controlled environment room and used as source material for this and related studies on natural durability. After the boards had equilibrated to a constant weight, two 2% by 25-mm- (1- by 1-in.-) square members were cut from the 1250-cm length of one board from each tree in heartwood, as close to the pith as possible. Two additional 25- by 25-mm-square members were cut from the length of the same board as close as possible to the sapwood edge of the heartwood. These members were used as source materials for blocks in this study and for stakes in another study.

The natural decay resistance of heartwood from these live and dead yellow-cedar trees was evaluated in the laboratory according to procedures defined in D 2017-81 (1). In the standard method, blocks of wood being evaluated are exposed in decay chambers to pure cultures of decay fungi. Simultaneously, blocks of wood lacking decay resistance are exposed to the same fungi. The test is continued until a weight loss of 60 percent occurs in the reference blocks of decay-susceptible wood. Then the resistance of the wood being evaluated is assessed on the basis of weight lost as a result of decay **(Table 3, Fig. 1).**

***TABLE 3.*** *– Criteria ,for classifying natural resistance of wood to decay fungi according to D 2017 (1).*

| Average weight loss[a] | Average residual weight | Indicated class of resistance to a specified test fungus |
|---|---|---|
| (%) | | |
| 0 to 10 | 90 to 100 | Highly resistant |
| 11 to 24 | 76 to 89 | Resistant |
| 25 to 44 | 56 to 75 | Moderately resistant |
| 45 or above | 55 or less | Slightly resistant or nonresistant |

[a] Weight loss of 60 percent has been achieved in reference wood that lacks decay resistance.

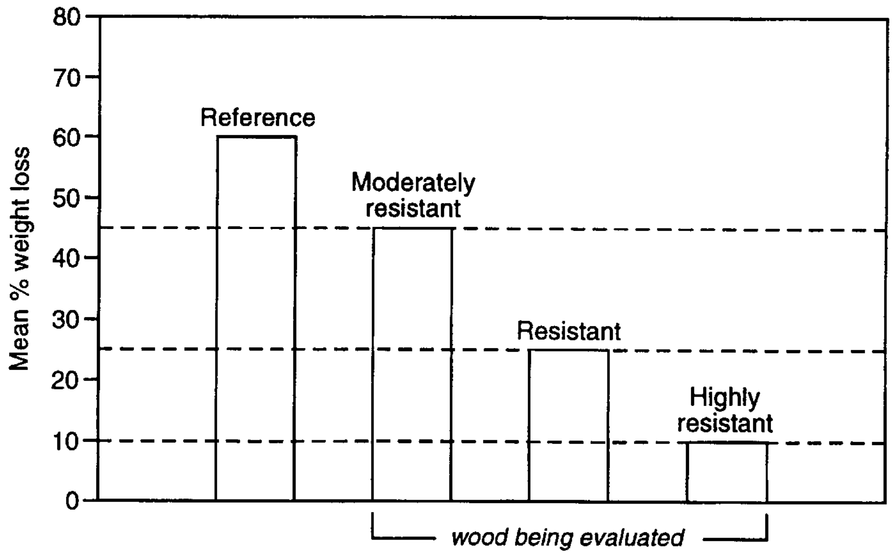


Figure 1. – Classification of natural decay resistance in subject wood when mean weight loss in reference wood has achieved 60 percent (1).

For this study, nine, 9-mm- (3/8-in.-) thick slices were cut from each 25- by 25-mm-square heartwood member that was closest to the pith and from each 25- by 25-mm-square heartwood member that was closest to the sapwood. Most of these blocks were from clear heartwood, but some stained heartwood was included because we were unable to sample only clear wood. The condition of the wood in each block was recorded. From each set of nine blocks, three replicate blocks were randomly selected for decay trials, with each of the three decay fungi used in this experiment. The identity of each block was followed throughout the experiment, and final results were scrutinized to determine whether the presence of stain in some blocks had a unique effect. Six replicate blocks from the sapwood of southern yellow pine *(Pinus* spp.) and six blocks from either heartwood or sapwood of Pacific silver fir *(Abies amabilis)* were used as reference nondecay-resistant softwoods with each fungus.

Reference woods and heartwood from yellow-cedar were challenged with three decay fungi. We used the following two brown-rot fungi that are specified in ASTM D 2017 for testing softwoods: *Gloeophyllum trabeum* Pers. ex. Fr. (ATCC No. 11539 {MSN 617}) and *Postia placenta* (Fr.) Cke. *(Poria placenta* (Fr.) M. Larson & Lomb.) (ATCC No. 11538 {MSN 698}); plus a water-conducting decay fungus: *Serpula himantioides* (Fr.:Fr.) Karst. Brown-rot fungi are the predominant decay fungi in softwood construction used aboveground. *S. himantioides* has been isolated from treated wood products in Forest Products Laboratory field test plots in southern Mississippi. It has also been reported on yellow-cedar in Alaska (6).

An analysis of variance of the percentage weight losses that occurred within the reference woods was completed separately from an analysis of variance of weight losses that occurred within yellow-cedar wood samples. Means within defined subsets were then tested for significance of difference using a Tukey Multiple-Range Test. With the reference woods, there was a significant interaction between wood species and fungus. Thus, weight loss data for the reference blocks had to be analyzed by isolate for each wood species. Numerous interactions occurred within the yellow-cedar woods; therefore, data were reviewed initially by fungus. Then a detailed analysis of results, by wood source, with *G. trabeum* was completed. We summarized results with *P. placenta* and *S. himantioides* by fungus without detailed analyses of the wood source because, with these two fungi, there were no significant differences between weight loss of the yellow-cedar and the reference woods. A detailed analysis of weight loss data in heartwood from live and dead snag class III trees that was challenged with *G. trabeum* is given because this heartwood was resistant to *G. trabeum.* Statistical analysis examined effects of years after mortality, tree size, radial position within the bole, and stain upon weight losses caused by *G. trabeum.* When sample sizes were small and uneven, such as that which occurred with comparisons of stained and unstained wood, the Wilcoxin rank test was used to test for significant differences.

## RESULTS

### REFERENCE WOODS

In southern yellow pine reference blocks, average weight losses caused by *G. trabeum* (59.6%) and *P. placenta* (62.0%) were not significantly different **(Figs. 2 and 3).** The weight loss caused by *S. himantioides* (43.9%) was significantly less than that caused by the other two fungi in pine. In Pacific silver fir, mean weight losses were significantly different among all fungi, to wit: *G. trabeum (70.5%) > P. placenta (63.0%) > S. himantioides* (50.2%). Both *G. trabeum* and *S. himantioides* caused significantly more decay in silver fir than in pine **(Figs. 2 and 4).** With *P. placenta,* the average weight losses in these two wood species were not significantly different **(Fig. 3).**

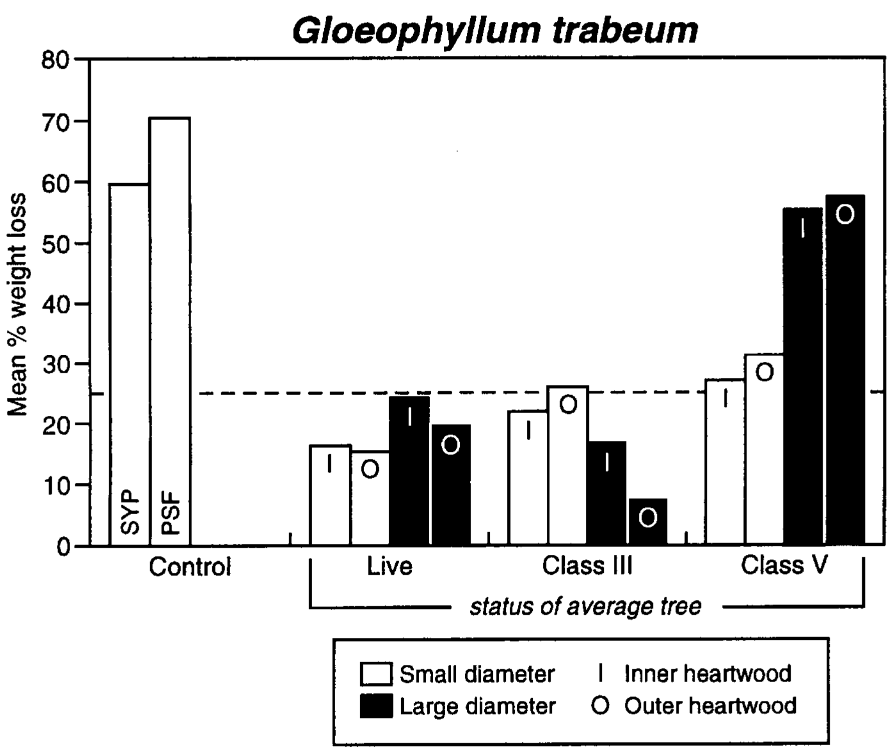


Figure 2. –Mean percentage weight loss caused by *G. trabeum* in heartwood from live and dead trees of yellow-cedar. Wood with weight loss of less than 25 percent is classified resistant.

*TABLE 4. – Average weight loss as a result of decay by G. trabeum.*

| Snag class | Average weight loss: Small tree diameter | Average weight loss: Large tree diameter |
|---|---|---|
| | (%) | |
| Live | 15.9 A[a] | 21.6 A |
| III | 21.6 A | 12.0 A |
| V | 29.2 A | 56.3 B |

[a] Averages within each diameter category (column) with the same capital letter are not significantly different. Averages within each tree class (line) with the same capital letter are not significantly different.

### YELLOW-CEDAR

Major differences occurred among fungi in their ability to decay yellow-cedar **(Figs. 2 through 4).** In general, the mean percentage weight loss was caused by *G. trabeum < S. himantioides < P. placenta.* For all tree class by diameter categories, except for heartwood from large class V trees, the mean percentage weight loss caused by *G. trabeum* was significantly less ($\alpha = 0.0001$) than that caused by the other two fungi. For woods from the large diameter class V trees, however, the average weight losses caused by all three fungi were comparable.

Resistance to attack by *G. trabeum* of heartwood from snag class V (trees dead 81 years) was significantly different from decay resistance of heartwood **(Fig. 2)** in live trees or in dead trees in snag class III (trees dead 26 years) **(Table 4).** Heartwood from live trees and snag class III trees was resistant to attack by *G. trabeum.* Heartwood from smaller diameter trees in snag class V was moderately resistant to *G. trabeum,* but heartwood from the larger diameter trees in snag class V was not. The average percentage weight loss of heartwood from live trees and trees dead approximately 26 years (snag class III) was less than 25 percent when subjected to decay by *G. trabeum* **(Fig. 2).** Mean percentage weight loss as a result of attack by *G. trabeum* was about 30 percent in heartwood from small-diameter class V trees and 56 percent in heartwood from large-diameter class V trees **(Table 4).**

For yellow-cedar heartwood challenged with *G. trabeum,* there was a statistically significant interaction between tree diameter and tree class, within the respective diameter categories. Significant differences were detected among tree classes in heartwood from the larger diameter trees **(Table 4),** but not among tree classes in wood from the smaller trees **(Table 4).** Within each tree class, the average percentage weight loss for heartwood from small and large stems was significant only for trees in class V **(Table 4).**

A comparison of data from wood with and without stain **(Table** 5) indicated that stained outer heartwood from live and class III trees was more prone to decay than unstained outer heartwood from those trees. There was no statistical evidence for the difference in decay susceptibility of stained and unstained inner heartwood. In unstained heartwood from the live and class III trees, the range of weight losses as a result of decay was greater in heartwood from the center of the tree (inner heartwood) than from the outer edge of the heartwood column. These distribution ranges are shown in box plots **(Fig. 5),** which depict the range from the 25th to the 75th percentiles within a box, the mean (a +), the median (line), and a 95 percent confidence interval (shaded area) about the median.

None of the higher average weight loss values as a result of attack by *P. placenta* and *S. himantioides* or by *G. trabeum* in heartwood from class V trees was due to the presence of stain. These values reflect the ability of the respective fungi to decay that heartwood.

None of the yellow-cedar heartwood was resistant to *P. placenta.* Similarly, none of the yellow-cedar heartwood evaluated was regarded as being resistant to *S. himantioides,* even though the targeted 60 percent weight loss was not achieved in the reference woods with that fungus. Weight losses in yellow-cedar heartwood samples subjected to *S. himantioides* were comparable with those observed in the reference woods. Mean percentage weight loss caused by *P. placenta* was greater than 50 percent in all heartwood samples **(Fig. 3).** *S. himantioides* caused an average weight loss of 45 to 50 percent in heartwood samples of yellow-cedar and in the reference woods **(Fig. 4).**

## DISCUSSION

Suhirman and Eaton (16) emphasized that durability against one organism or group of organisms cannot be used to predict durability against other organisms. The work by Smith (14) and results from our study provide an opportunity to interpret this principle with respect to possible differences in the resistance of clear yellow-cedar heartwood to soil-inhabiting wood-decay fungi compared with decay fungi that attack wood used aboveground. *P. incrassata* and *S. himantioides,* against which clear heartwood is not resistant, are soil-inhabiting, water-conducting brown-rot fungi. Heartwood of yellow-cedar is also susceptible to decay by *P. placenta.* This fungus has been isolated from Douglas-fir, spruces, and frequently from stumps, trunk, or butt rots or from products exposed to continuous wetting. Examples of such products are experimental stakes in ground contact, mine shafts, and utility

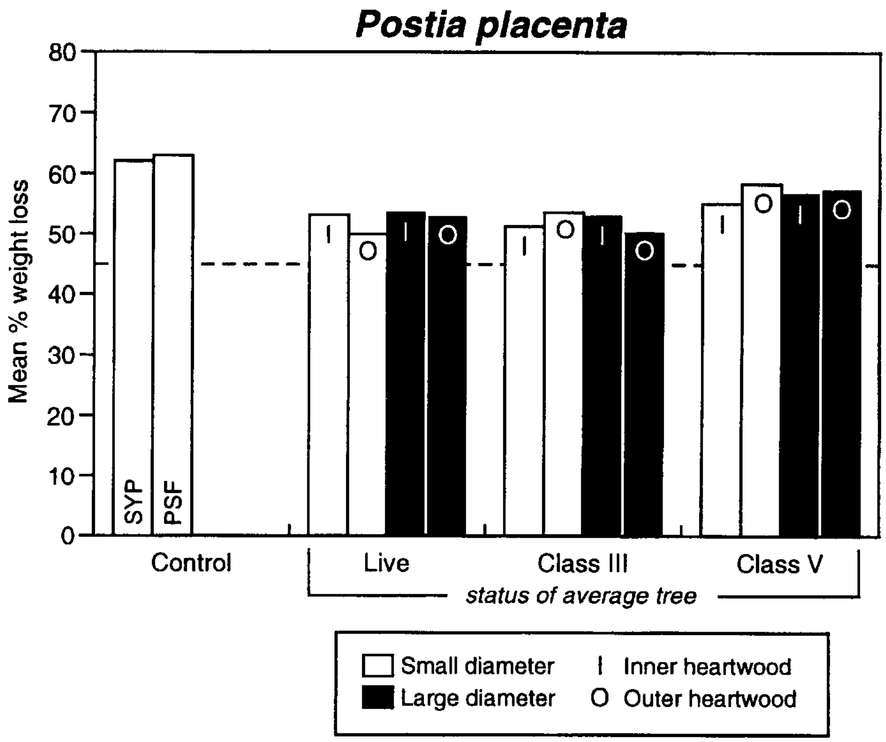


Figure 3. – Mean percentage weight loss caused by *P. placenta* in heartwood from live and dead trees of yellow-cedar.

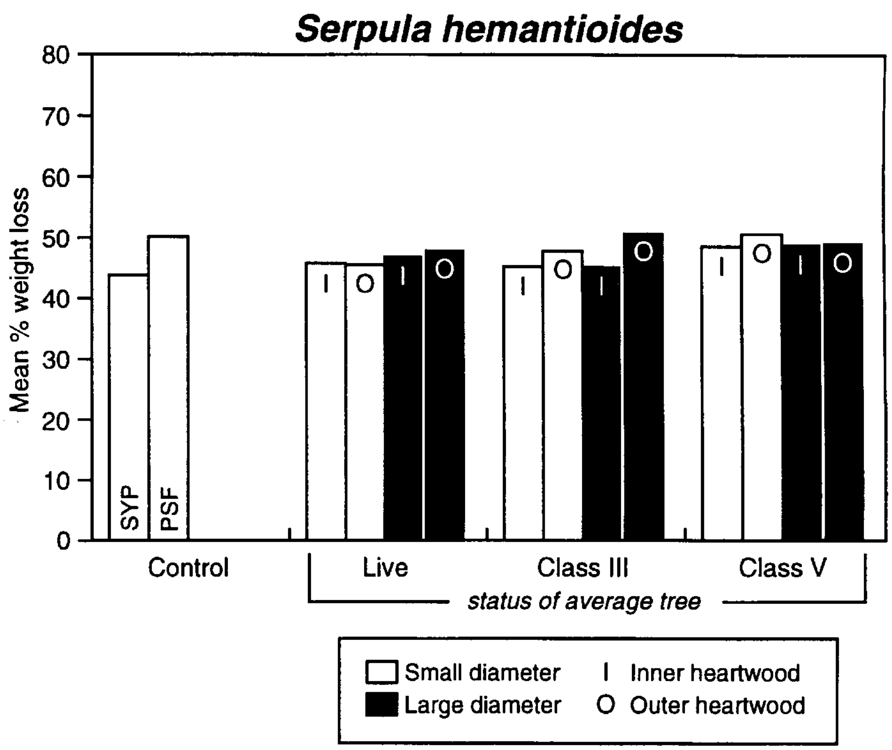


Figure 4. – Mean percentage weight loss caused by *S. himantioides* in heartwood from live and dead trees of yellow- cedar.

*TABLE 5. – Avenge weight loss as a result of decay by G. trabeum in stained and unstained wood located near the pith center (inner) or the outer edge of the heartwood (outer).*

| | Average weight loss | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Small tree diameter | | | | Large tree diameter | | | |
| | Inner | | Outer | | Inner | | Outer | |
| Snag class | Not stained | Stained | Not stained | Stained | Not stained | Stained | Not stained | Stained |
| | (%) | | | | | | | |
| Live | 16.3 | 16.7 | 8.2 | 21.8 | 23.2 | 33.2 | 16.9 | 22.7 |
| III | 17.1 | 59.0 | 6.3 | 36.2 | 16.7 | -- | 7.2 | 7.6 |
| V | 22.7 | 66.5 | 31.7 | 29.6 | 49.8 | 56.0 | 56.7 | 62.7 |

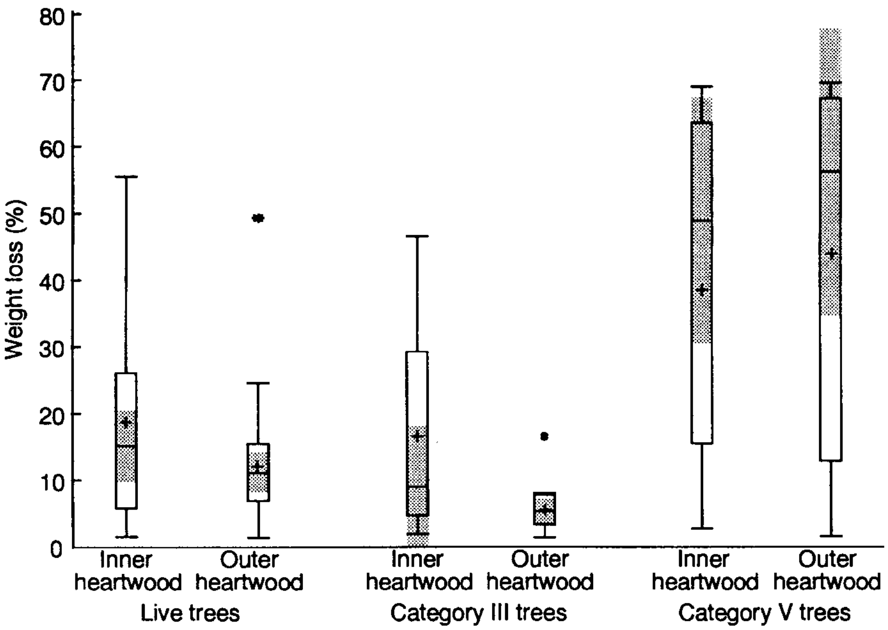


Figure 5. – Distribution of percentage weight loss caused by *G. trabeum* in unstained inner and outer heartwood from live and categories III and V yellow-cedar trees. * = extreme outlier: • = outlier.

poles. Clear heartwood from live trees and trees dead less than 80 years has resistance to *L. saepiaria* and *G. trabeum,* brown-rot fungi that attack wood in aboveground construction. These fungi have been isolated from mostly softwoods in a variety of exposures, but they are particularly important in products, such as millwork, outdoor steps, balconies, and wood seating, that are used aboveground in exterior environments and are subjected to intermittent wetting. This suggests that heartwood from this source would have practical application where durability is desired in wood products used aboveground and subjected to intermittent wetting. We are unaware of other studies that have characterized the durability of heartwood in trees up to 80 years following death.

Unstained heartwood from live trees and trees dead less than 80 years is resistant to *G. trabeum,* but that resistance diminishes thereafter. It is puzzling as to why this loss of resistance appeared to progress more quickly in trees of the larger diameter class than in the smaller diameter class. Additional studies are being conducted to determine if decay resistance of wood can be related directly to extractive content. If so, this relationship will be examined to learn if loss of extractives will explain the ultimate loss of natural durability to decay fungi.

There is evidence that in the outer heartwood, stained wood is more prone to decay than is clear wood. This difference between stained and unstained wood in decay susceptibility was not observed in the inner heartwood. The rather large tree-to-tree variation in decay resistance of unstained inner heartwood probably explains the absence of a statistical difference in susceptibility of stained and unstained inner heartwood to decay. This tree-to-tree variation could also have practical importance in products. Whereas the categorization of woods into natural durability classes is referenced to the average values, the inner heartwood from some trees is one or more categories less resistant than the outer heartwood. Characterization of the distance that this wood extends from the pith, either in absolute physical units or as a specified number of annual rings, might aid in quality control of subsequent products produced from these trees.

## Conclusions

Results from this and a previous study (14) suggest that the natural durability against decay fungi of clear heartwood from living yellow-cedar trees and from yellow-cedar trees that have been dead less than 80 years is adequate to have practical application for products used aboveground and subjected to intermittent wetting. Heartwood of live and dead yellow-cedar trees is not resistant to decay by *Postia placenta* and *Serpula himantioides.* These results, in concert with published studies, indicate that yellow-cedar heartwood products used in ground contact may not provide long-term (decades) service. The actual performance would probably reflect an interaction of the product size and the microbial ecosystem at the use site.

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